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Estimates of the Cost of New Electricity Generation in the South

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Abstract: Future demand for electricity can be met with a range of technologies, with fuels including coal, nuclear, natural gas, biomass and other renewables, as well as with energy efficiency and demand management approaches. Choices among options will depend on factors including capital cost, fuel cost, market and regulatory uncertainty, greenhouse gas emissions, and other environmental impacts. This paper estimates the costs of new electricity generation. The approach taken here is to provide a transparent and verifiable analysis based mainly on recent data provided to public utility commissions by electric utilities. As new data become available, this analysis can be readily updated.

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Executive Summary

Estimated costs of electricity from new nuclear, supercritical pulverized coal, natural gas combined cycle (NGCC), and biomass power plants are shown in Figure 1 and Table 1. The range of costs for nuclear, coal, and natural gas power plants reflect the range of utility cost estimates for proposed new plants. The estimate for electricity production from supercritical pulverized coal power plants includes the cost of transporting coal to the southeast region of the United States, and the estimate for natural gas includes fuel costs from $5/MMBtu to $7/MMBtu. The data for the nuclear, pulverized coal, natural gas, and biomass estimates are primarily from recent commercial filings with public utility commissions; all of the nuclear and biomass plant data are for plants proposed in the southeast. We have also developed an estimate for integrated gasifier combined cycle (IGCC) coal plants; in the absence of adequate data on commercial proposals we have drawn only on model estimates; when we can develop more robust IGCC estimates we will include them in the comparative analysis. Costs are adjusted to 2010 dollars using an inflation rate of 3% per annum.

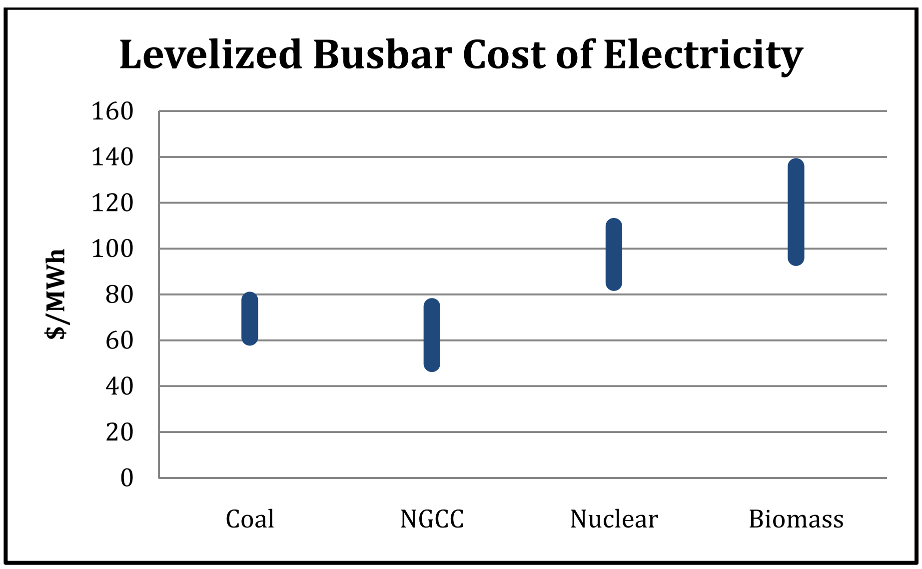

Figure 1: Estimated Levelized Busbar Cost of Electricity from New Power Plants

Figure 1 shows that nuclear and biomass are currently the most expensive of the technologies shown. There is a considerable range of costs, so that in some situations coal may be less expensive than natural gas (NGCC) plants, and the least expensive nuclear plants can nearly match the high end of the cost of coal and natural gas. The costs shown in Figure 1 and Table 1 do not take into account the potential future costs of greenhouse gas emissions or other external costs, which would tend to raise the costs of coal and natural gas plants, while leaving nuclear and biomass costs largely unchanged. These costs also do not take into account nonmonetary aspects of power generation such as environmental impacts and water usage.

Table 1 shows that nuclear and biomass have the highest capital cost, and nuclear has the lowest fuel cost, while natural gas (NGCC) has the lowest capital cost and the highest fuel costs. These differing cost structures affect the economics of each technology: the economics of nuclear power are strongly dependent on the capital costs of plant construction, while the economics of natural gas power are strongly dependent on the price of natural gas. The costs of electricity shown in Figure 1 and Table 1 are busbar levelized costs and do not include the costs of transmission and the costs of building transmission capacity for the new plants.

Table 1: Estimated Levelized Busbar Cost of Electricity from New Power Plants

Technology	Levelized Cost of Energy ($2010/MWh)	Overnight Capital Cost ($2010/kW)	Fuel Cost ($2010/MMBtu)
Nuclear	80 - 103	3,800 – 5,200	0.75
Coal	59 - 75	2,000 – 3,000	2.30
NGCC	49 - 74	600 – 1,300	5 - 7
Biomass	92 - 131	4,650 – 4,900	0.75 – 4.0

The Electric Power Research Institute has also estimated of the cost of new electricity generation (EPRI 2009). The EPRI estimates, shown in Table 2 converted from $2008 to $2010, are comparable to our estimates for coal and biomass, but are lower for nuclear power and considerably higher for natural gas.

Table 2: Comparison with EPRI Estimates for Levelized Busbar Cost of Electricity

Technology	This Study ($2010/MWh)	EPRI Estimates ($2008/MMBtu)	EPRI Estimates ($2010/MMBtu)
Nuclear	80 - 103	89	94
Coal	59 - 75	70	74
NGCC	49 - 74	79-94	84 - 100
Biomass	92 - 131	82-95	87 - 101

These costs would change if there were a price associated with carbon dioxide emissions. The production of 1 MWh of electricity results of the lifecycle greenhouse gas emissions of approximately 1 tonne of CO_2-equivalent for coal-fired power plants and approximately 0.57 tonnes for natural gas fired power plants (Jaramillo et al. 2007). Although production of electricity from nuclear power or from biomass results in no net direct emissions of carbon dioxide, the activities required to make or gather the fuel do result in some small net emissions, on the order of 0.05 tonnes/MWh for nuclear, and at least 0.005 tonnes/MWh for biomass (taking into account biomass transport). The effects of carbon prices on busbar electricity costs are shown in Figure 2. Although there is significant uncertainty in the cost of all the options, at about \$30/tonne of CO_2 coal-derived electricity becomes as expensive as nuclear or biomass-derived electricity. At about \$60/tonne, natural gas derived electricity becomes as expensive as nuclear- or biomass-derived electricity.

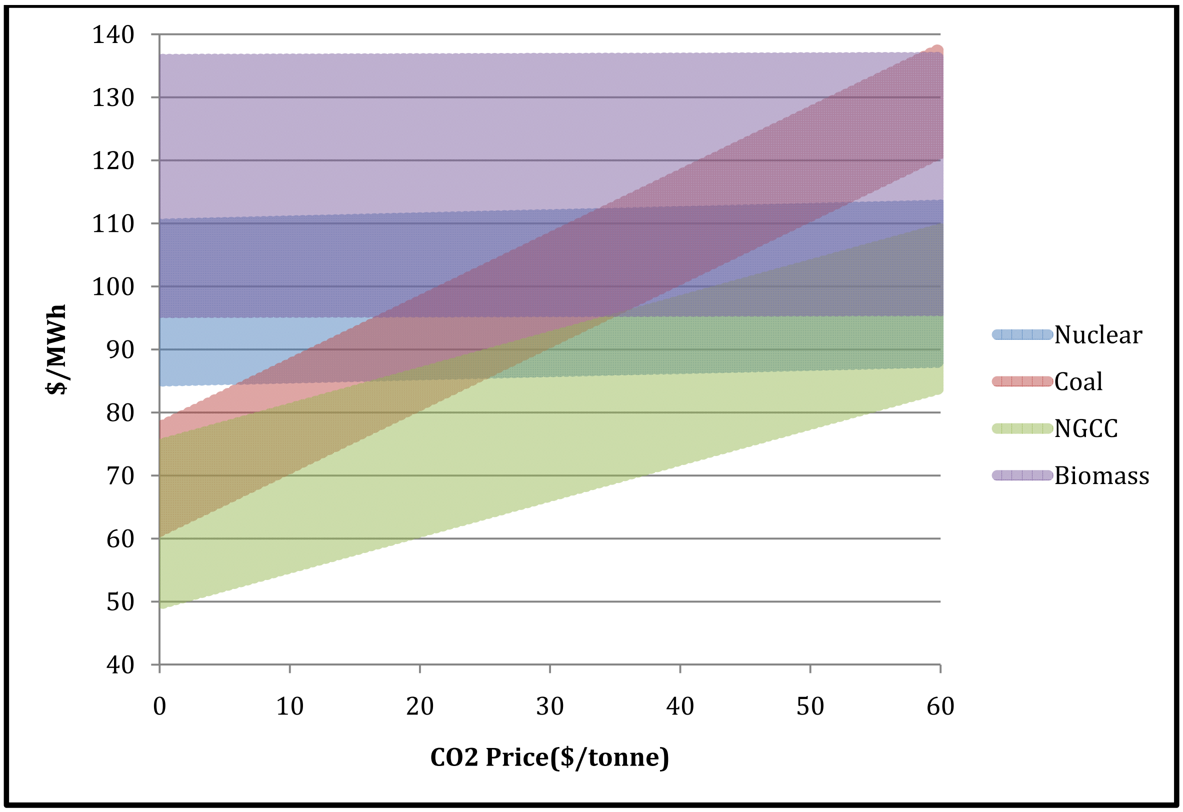

Figure 2: Effect of CO_2 prices on costs of new electricity generation

Table 3 and Figure 3 show the estimated retail price of electricity from new power plants, including estimated costs for building new transmission capacity, under the assumption that retail electricity prices are 4 ¢/kWh higher than the production costs. The additional 4 ¢/kWh is used to account for the costs of transmission and distribution and for generators' revenue margins.

Table 3: Estimated Retail Price of Electricity from New Power Plants

Technology	Electricity Price (¢2010/kWh)
Nuclear	13 - 15
Coal (SC)	10 - 12
NGCC	9 - 12
Biomass	14 - 18

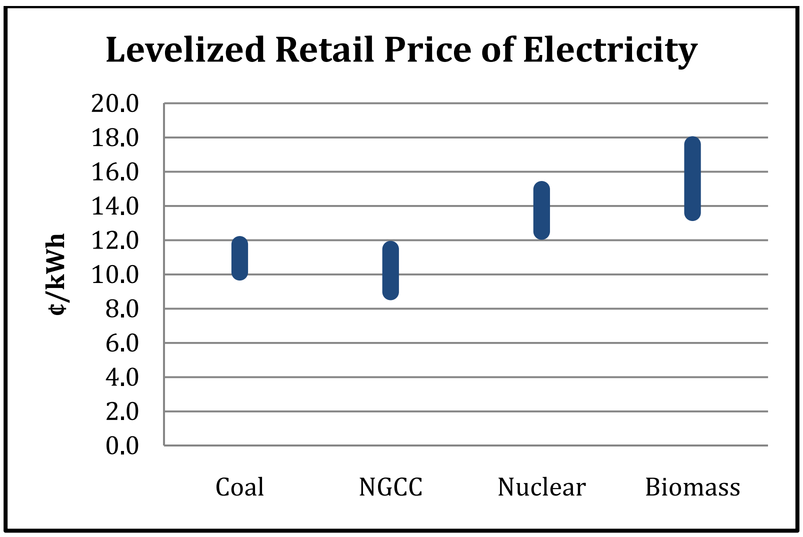

Figure 3: Estimated Retail Price of Electricity from New Power Plants

Cost of New Nuclear Electricity Generation

Capital Cost. Public filings for new nuclear power plants are available for Florida Power and Light, South Carolina Energy and Gas, Progress Energy Florida, and Georgia Power. To provide some consistency among the estimates, we have identified the overnight capital cost, that is, the capital cost excluding financing costs, and then we have explicitly included the same financing costs, fuel costs, and other costs for all the plants to provide an estimate of both wholesale electricity costs and retail electricity prices on a consistent basis.

Florida Power and Light's estimate is based on the construction of two Westinghouse AP1000 units for a total capacity of 2,200 MW. According to filings with the Nuclear Regulatory Commission on June 30, 2009, the total overnight cost is estimated to be $6.8 billion, $7.9 billion, or $10 billion in 2007 dollars depending on the owner scope and range of transmission (FPL 2009). When transmission and general plant costs are excluded, total overnight cost estimates are $5.9 billion, $6.8 billion, $8.7 billion in 2010 dollars. This translates to an overnight cost of $2,700/kW, $3,100/kW, or $3,900/kW depending on the scenario. When transmission and general plant costs are included, the overnight costs become $3,400/kW, $3,900/kW and $5,000/kW. The average overnight costs of $3,200/kW and $4,100/kW including and excluding transmission and general plant costs are shown in Tables 3 and 4, respectively.

South Carolina Energy & Gas' estimate is based on the construction of two Westinghouse AP1000 units at V.C. Summer Nuclear Station near Jenkinsville, South Carolina. The plant would be 55% owned by South Carolina Electric and Gas. The total project cash flow for SCE&G is $5.4 billion excluding transmission (Exhibit F Chart A, p. 57, May 30 2008), implying a total cost of $10 billion in 2007 dollars, for 2,234 MW (SCE&G, 2005). Assuming that the other stakeholders' costs are proportional to those of SCE&G, total costs increase to $11 billion in 2007 dollars including transmission project costs. This is an overestimate of the overnight cost because it includes contingency and project cost escalation; the details of that calculation were redacted. Using $10 billion and $11 billion as an upper limit estimate, we arrive at approximately $4,800/kW without transmission and 5,400 $/kW with transmission in 2010 dollars.

Progress Energy Florida's estimate is based on its August 12, 2008 filing with the Florida Public Service Commission for Levy Nuclear Units 1 and 2, which would consist of two Westinghouse AP1000 nuclear-fueled units with in-service dates of 2016 and 2017. Each unit is 1,100 MW for a total nameplate capacity of 2,200 MW. The estimated overnight costs are $5,144/kW for Unit 1 and $3,376/kW for Unit 2, bringing the total estimated cost to $14.1 billion (p. 10). This total would include $3.245 billion in AFUDC (allowance for funds used during construction). Additionally, transmission costs are estimated to be between $1.85 billion and $2.5

billion, excluding AFUDC (PEF, 2008). Assuming these costs are in 2008 dollars[1], the average of the overnight costs, $4,500/kW in 2010 dollars, is shown in Table 4. The overnight cost of the plant from the provided costs of $5,144/kW and $3,376/kW is $9.37 billion in 2008 dollars. When transmission costs are excluded, the overnight cost of the plant is between $6.9 billion and $7.5 billion in 2007 dollars, corresponding to an average of $3,500/kW in 2010 dollars as shown in Table 3.

Georgia Power's estimate is based on its August 2008 filing with the Georgia Public Service Commission. The proposal is to build two Westinghouse AP1000 reactors with a total nameplate capacity of 2,200 MW. The ownership would be 45.7% Georgia Power, 30% Oglethorpe, 22.7% MEAG, and 1.6% Dalton Utilities. Total in-service cost for Georgia Power is estimated to be $4.53 billion if the construction-work-in-progress (CWIP) funding is allowed, and $6.45 billion otherwise (Georgia Power, 2008). Assuming the cost structure is the same for all owners, the full cost would be, without CWIP, $14.1 billion, for $6,400/kW including financing. Note that the total cost, including financing, is the same as that estimated by Florida Progress Energy, and that the filings were both made in August 2008. If the financing and transmission costs and for Progress Energy Florida and Georgia Power are the same, then the overnight costs for the Georgia Power units would average $4,500/kW including transmission costs and $3,500/kW excluding transmission costs in 2010 dollars.

Tables 4 and 5 summarize the projected overnight costs with and without transmission costs for the four proposed US nuclear power plants.

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[1] The dollar year was not specified in the filing.

Table 4: Overnight Costs Excluding Transmission for Proposed Nuclear Plants

Primary Owner	Plant	Design	Capacity (MW)	Projected Commercial Operation Date	Overnight Cost in 2010 US$/kW
Florida Power & Light	Turkey Point 6 & 7	AP1000	2,200	2018-2020	3,200
SCE&G	VC Summer 2 & 3	AP1000	2,234	2016-2019	4,800
Progress Energy Florida	Levy County 1 & 2	AP1000	2,200	2016-2017	3,500
Georgia Power	Vogtle 3 & 4	AP1000	2,200	2016-2017	3,500

Table 5: Overnight Costs Including Transmission for Proposed Nuclear Plants

Primary Owner	Plant	Design	Capacity (MW)	Projected Commercial Operation Date	Overnight Cost in 2010 US$/kW
Florida Power & Light	Turkey Point 6 & 7	AP1000	2,200	2018-2020	4,100
SCE&G	VC Summer 2 & 3	AP1000	2,234	2016-2019	5,400
Progress Energy Florida	Levy County 1 & 2	AP1000	2,200	2016-2017	4,500
Georgia Power	Vogtle 3 & 4	AP1000	2,200	2016-2017	4,500

The costs shown in Tables 4 and 5 reflect a considerable increase in costs over the past 15 years. Data on nuclear power plants built in Japan and in the Republic of Korean from 1994 to 2006 are consistent with a 15% annual increase in capital costs (Du and Parson 2009).

Based on the projected costs of the US nuclear power plants shown in Tables 4 and 5, we estimate the overnight capital cost of new nuclear power plants to be approximately $3800/kW without transmission costs and $4,600/kW including transmission costs, with a range of more than 15%. Other studies have arrived at both higher and lower estimates: Black & Veatch (2007) estimate a capital cost of $3,169/kW in 2006 dollars for the year 2010. Lazard Ltd (2008) estimate a capital cost of $5,750/kW to $7,550/kW in 2008 dollars. The financing of the plant can have a large effect on the reported capital cost. Du and Parsons and Lazard Ltd factor the cost of debt, cost of equity, and depreciation into their calculation of capital costs. Black & Veatch use the overnight capital cost, omitting interest and the cost of equity.

Operation and Maintenance Costs: Operation and maintenance costs occur each year that the plant is in operation and are often disaggregated into fixed and variable costs. Estimates of O&M costs from various sources are shown in Table 6. Du and Parsons use a real escalation rate for O&M costs of 1.0%. Lazard Ltd uses an annual escalation rate of 2.5% for O&M costs.

Table 6: Nuclear O&M Costs

	O&M Costs	
Source	**Fixed ($2010/MW)**	**Variable ($2010/MWh)**
Du and Parsons, 2009	61	0.46
Black &Veatch, 2007	101	0.56
Lazard Ltd, 2008	13.6	11.67

Fuel Costs: Fuel costs estimated by various sources are shown in Table 7. Du and Parsons use a real escalation rate of fuel costs of 0.5%. Lazard Ltd uses an annual escalation rate of 2.5% for fuel costs. Figure 4 shows the significant recent increase in nuclear fuel costs.

Table 7: Nuclear Fuel Costs

Source	**Fuel Cost ($2010/MMBtu)**
Du and Parsons, 2009	0.73
Black &Veatch, 2007	0.68*
Lazard Ltd, 2008	0.53

*Black & Veatch report a levelized fuel cost

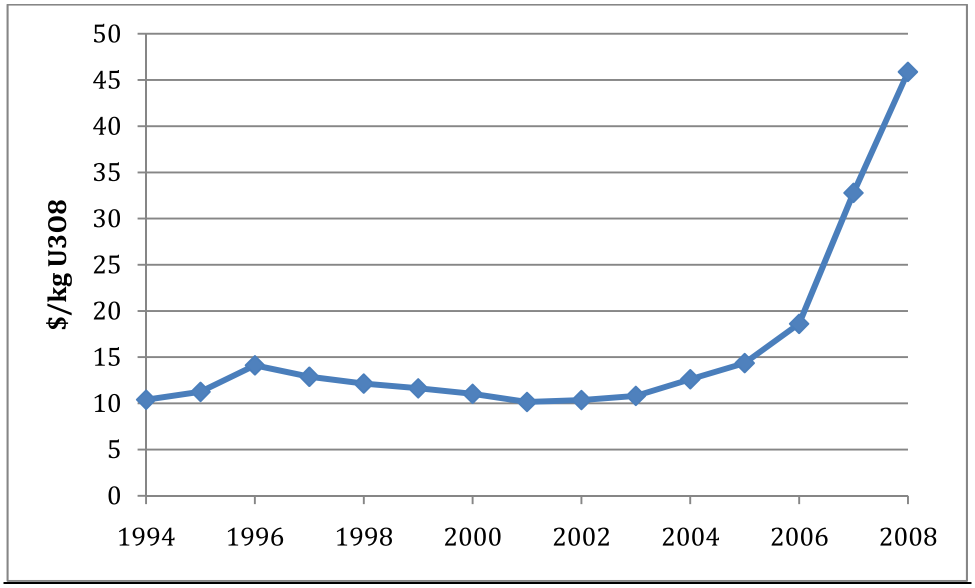

Figure 4: Triuranium Weighted-Average Prices[2]

Other Costs: Several other costs are sometimes included when calculating the levelized cost of electricity. Costs that are sometimes included are incremental capital costs, waste fees, and decommissioning costs. Du and Parsons use an incremental capital cost of $40/kW/year. FPL certified that financial assurance of approximately $376 million per unit would be provided for decommissioning (FPL, 2009). Section 302 of the Nuclear Waste Policy Act of 1982 states that civilian nuclear power reactors must pay a spent fuel fee of 1.0 mil/kWh ($1/MWh). This fee was also used in Du and Parsons (2009) and PEF (2009). The waste disposal fee is insignificant in comparison to the uncertainty considered in this report and is omitted.

Levelized Cost of Electricity: Table 8 shows our estimate of the levelized busbar cost of electricity from new nuclear power plants. We estimate that the cost of electricity is approximately $85/MWh to $110/MWh.

[2] http://www.eia.doe.gov/cneaf/nuclear/umar/summarytable1.html

Table 8: Estimated Cost of Electricity from New Nuclear Power Plants

Nameplate Capacity (MW)	2,200
Capacity Factor	0.9
Nominal Discount Rate	7%
Book Life (years)	30
Plant Life (years)	60
Heat Rate (Btu/kWh)	10,400
Capital Cost ($/kW)	3,800 – 5,200
Fixed O&M ($/kW)	80
Variable O&M ($/MWh)	0.5
Fuel Cost ($/MMBtu)	0.75
Calculation Type	Carrying Charge = 18%
LCOE ($/MWh)	85 - 110

The levelized cost of electricity as reported by other sources is shown in Table 9. For comparison purposes, costs are inflated at 3% annually to show 2010 dollars.

Table 9: Estimated Cost of Electricity from New Nuclear Power Plants

Source	LCOE($2010/MWh)
Du and Parsons, 2009	92
Black &Veatch, 2007	100
Lazard Ltd, 2008	104 - 134

<u>Retail Price</u>: Assuming the price of electricity sold to the customer is approximately 4 ¢/kWh more than the cost to generate the electricity, the price of electricity from a new nuclear plant is about ¢12.5/kWh to ¢15.0/kWh.

Cost of New Supercritical Pulverized Coal Electricity Generation

Capital Cost: Public filings are available for Duke Energy Carolina's Cliffside Generating Station, SWEPCOs' John W. Turk power plant, Florida Power and Light's Glades power plant, and AMP Ohio's American Municipal Power generating station. Tables 10 and 11 show the projected overnight costs including and excluding transmission costs for the four proposed coal-fired power plants; each estimate is discussed below.

Duke Energy Carolinas' estimate is based on the addition of one 800 MW supercritical pulverized coal unit at the Cliffside Generating Station. In filings with the North Carolina Utilities Commission, the capital cost is estimated to be $1.8 billion, including $550 million to $600 million in Allowance for Funds Used During Construction (AFUDC) (Duke Power, 2005, 2008). Excluding AFUDC gives a total overnight cost of $1.2 billion. Assuming that this cost is in 2008 dollars, the overnight cost in 2010 dollars is $1600/kW. Due to the confidentiality of cost details in the filings, transmission costs cannot be excluded from the total overnight cost.

SWEPCO's estimate is based on the construction of a 600 MW ultra-supercritical pulverized coal unit at John W. Turk, Jr. Power Plant. SWEPCO would hold an expected 73% share in the project. Filings with the Arkansas Public Service Commission in December 2006 estimate the total capital cost to be $1.343 billion, excluding AFUDC. Additionally, SWEPCO estimated a cost of $136 million for transmission facilities (SWEPCO, 2006). Assuming the other owners will share the expense of transmission facilities, the total cost of transmission facilities is $186 million. This brings the total cost of the project to $1.5 billion. Under the assumption that these costs are in 2006 dollars, the overnight cost, excluding transmission costs and AFUDC, is $2,500/kW in 2010 dollars. The overnight cost including transmission costs is $2,900/kW in 2010 dollars.

Florida Power and Light's cost estimate is based on the proposed construction of two 980 MW ultra-supercritical pulverized coal units at Glades Power Park. This project was cancelled in 2009. Filings with the Florida Public Service Commission in February 2007 estimated the cost of the units to be $3.46 billion for Unit 1 and $2.24 billion for Unit 2 in 2013 and 2014 dollars, respectively. This gives a total cost of $5.7 billion, or $4.26 billion excluding the $396 million for transmission interconnection and integration and $1.04 billion in AFUDC (FPL, 2007). This provides an estimated overnight cost of $2,000/kW in 2010 dollars. When transmission is included, the estimated overnight cost is $2,500/kW.

AMP Ohio's estimate is based on the construction of two 480 MW supercritical pulverized coal units at the American Municipal Power Generating Station in Meigs County, Ohio. An update by R.W. Beck in October 2008 estimates the total construction cost including transmission costs to be $3.257 billion. Assuming that this cost is in 2008 dollars, the overnight cost in 2010 dollars is $3,600/kW. Transmission costs are not specified and cannot be disaggregated from the total construction cost. The cost estimates for this project were increased in May 2009, and further increased in November 2009, at which point the project was cancelled (AMP 2009), so the estimate in Table 11 underestimates actual costs.

Table 10: Overnight Costs Excluding Transmission Costs for Proposed Supercritical and Ultra-Supercritical Coal Plants

Owner	Name	Design	Capacity (MW)	Projected Commercial Operation Date	Overnight Cost 2010$/kW	Estimate Date
Duke Energy	Cliffside	SC PC	800	2012	N/A	Feb-09
SWEPCO	John W. Turk Jr.	USC PC	600	2012	2,500	Dec-06
Florida P&L	Glades	USC PC	1,960	2013-2014	2,000	Feb-07
AMP Ohio	Meigs County	SC PC	960	2014	N/A	Oct-08

Table 11: Overnight Costs Including Transmission Costs for Proposed Supercritical and Ultra-Supercritical Coal Plants

Owner	Name	Design	Capacity (MW)	Projected Commercial Operation Date	Overnight Cost 2010$/kW	Estimate Date
Duke Energy	Cliffside	SC PC	800	2012	1,600	Feb-09
SWEPCO	John W. Turk Jr.	USC PC	600	2012	2,900	Dec-06
Florida P&L	Glades	USC PC	1,960	2013-2014	2,500	Feb-07
AMP Ohio	Meigs County	SC PC	960	2014	3,600	Oct-08

Based on these estimates, the average overnight cost is $2500/kW, ranging from $1600 to $3600.

Operation and Maintenance Costs: Operation and maintenance costs occur each year that the plant is in operation and are often disaggregated into fixed and variable costs. Estimates of O&M costs from various sources are shown in Table 12.

Table 32: Supercritical Pulverized Coal O&M Costs

Source	Fixed ($2010/kW)	Variable ($2010/MWh)
DOE, 2007	25.18	4.87
Black & Veatch, 2007	35.30	1.70
Katzer, et. Al., 2007		8.69
Du and Parsons, 2009	26.23	3.90

Fuel Costs: The cost of coal for a power plant depends on the type of coal used, and the transportation distance and cost. Delivered coal prices in the South Atlantic states have historically been slightly less than $0.50/MMBtu higher than the national average, while delivered coal prices in the East South Central states have been about $0.25/MMBtu higher than the national average. Transportation costs for western Powder River Basin coal and increased global demand for eastern Appalachian coal have forced delivered coal prices higher in the southeast as compared with the rest of the United States (US DOE 2009). For example, the national average delivered coal price was $2.22/MMBtu from January through October 2009, but was $3.26/MMBtu and $2.45/MMBtu in the South Atlantic and East South Central states, respectively.

Transport cost estimates also suggest a higher coal prices in the southeast than elsewhere. For example, low sulfur Powder River Basin coal, from Montana and Wyoming, cost about $10/short ton in 2009 (US DOE 2010). Rail transportation costs about 0.2¢/ton-mile in 2010 dollars (US DOE 2000). Transportation to Georgia or other parts of the southeast, a distance of approximately 1500 miles or 2300 km, therefore adds about $30/ton to the fuel cost. Powder River coal has an average energy content of 8800 Btu/lb, so the delivered cost of this coal to a distance of about 1500 miles is approximately $2.30/MMBtu. Central Appalachian coal costs about $52/ton in 2009 and has an energy content of 12,500 Btu/lb (US DOE 2009). With a transportation distance of about 300 miles, the delivered cost is approximately $2.30/MMBtu.

Other Costs: Several other costs are sometimes included when calculating the levelized cost of electricity, including incremental capital costs and decommissioning costs. Du and Parsons use an incremental capital cost of $27/kW/year.

Levelized Cost of Electricity: Table 13 shows our estimate of the levelized busbar cost of electricity from new supercritical pulverized coal power plants.

Table 13: Estimated Cost of Electricity from New Supercritical Coal Power Plants

Nameplate Capacity (MW)	1,000
Capacity Factor	0.85
Nominal Discount Rate	7%
Book Life (years)	30
Plant Life (years)	50
Heat Rate (Btu/kWh)	9000
Capital Cost ($/kW)	2,000 – 3,000
Fixed O&M ($/kW)	30
Variable O&M ($/MWh)	4
Fuel Cost ($/MMBtu)	2.30
Calculation Type	Carrying Charge = 15%
LCOE ($/MWh)	61 - 78

<u>Retail Price</u>: Assuming the price of electricity sold to the customer is approximately 4 ¢/kWh more than the cost to generate the electricity, the price of electricity from a new super-critical or ultra-supercritical coal plant is about 10.1¢/kWh to 11.8¢/kWh.

Cost of New Integrated Gasification Combined Cycle (IGCC) Coal Electricity Generation

Capital Cost. Currently there are no proposed or existing IGCC commercial power plants on which to base estimates of costs. Only prospective estimates are available, as shown in Table 14. Since planned IGCC projects have been cancelled due to concerns over costs, the estimates in Table 14 may underestimate the actual costs.

In filings with the Mississippi Public Service Commission, Mississippi Power proposed to build a 582 MW IGCC plant in Kemper County. The plant was reported to cost $2.2 billion and operation was expected to begin in late 2013. Assuming the $2.2 billion is in 2009 dollars, the cost of this plant would be approximately $3,900/kW in 2010 dollars (Southern Company, 2009).

Rosenberg (2005) reports capital costs from demonstration plants, published estimates, and regulatory filings. Among the regulatory filings and demonstration plants, capital costs range from roughly $1,500/kW to $1,900/kW. Assuming these costs are in 2000 dollars and 2003 dollars, respectively, the overnight cost is $2,000/kW to $3,000/kW in 2010 dollars.

The U.S. Department of Energy modeled several IGCC configurations using the ASPEN Plus modeling system (US DOE, 2007). Modeled capital costs range from around $1,900/kW to $2,200/kW when updated to 2010 dollars.

Black & Veatch (2007) estimated the capital cost of IGCC plants in 2010 to be approximately $3,200/kW in 2010 dollars.

None of the sources explicitly include transmission costs.

Table 14: Reported Overnight Costs for IGCC

Source	Reported Overnight Cost ($2010/kW)
Rosenberg (2005)	2,000 – 3,000
DOE (2007)	1,900 – 2,200
Black & Veatch (2007)	3,200
Mississippi Power (2009)	3,900

Operation and Maintenance Costs: Operation and maintenance costs occur each year that the plant is in operation and are often disaggregated into fixed and variable costs. Estimates of O&M costs from various sources are shown in Table 15.

Table 15: IGCC O&M Costs

Source	Fixed ($2010/kW)	Variable ($2010/MWh)
Rosenberg (2007)	22.9	3.9
DOE (2007)	38.5	7
Black & Veatch (2007)	42.9	4.4

Fuel Costs: The cost of coal for a power plant depends on the type of coal used, and the transportation distance and cost. For example, low sulfur Powder River Basin coal, from Montana and Wyoming, cost about $10/short ton in 2009 (US DOE 2010). Rail transportation costs about 0.2¢/ton-mile in 2010 dollars (US DOE 2000). Transportation to Georgia or other parts of the southeast, a distance of approximately 1500 miles or 2300 km, therefore adds about $30/ton to the fuel cost. Powder River coal has an average energy content of 8800 Btu/lb, so the delivered cost of this coal to a distance of about 1500 miles is approximately $2.30/MMBtu. Central Appalachian coal costs about $52/ton in 2009 and has an energy content of 12,500 Btu/lb (US DOE 2009). With a transportation distance of about 300 miles, the delivered cost is approximately $2.30/MMBtu.

Other Costs: Several other costs are sometimes included when calculating the levelized cost of electricity, including incremental capital costs and decommissioning costs.

Levelized Cost of Electricity: Table 16 shows our estimate of the levelized busbar cost of electricity from new IGCC pulverized coal power plants.

Table 16: Estimated Cost of Electricity from New IGCC Plants

Nameplate Capacity (MW)	550
Capacity Factor	.85
Nominal Discount Rate	7%
Book Life (years)	30
Plant Life (years)	50
Heat Rate (Btu/kWh)	8,700
Capital Cost ($/kW)	3,800
Fixed O&M ($/kW)	40
Variable O&M ($/MWh)	5
Fuel Cost ($/MMBtu)	2.30
Calculation Type	Carrying Charge = 15%
LCOE ($/MWh)	92

Retail Price: Assuming the price of electricity sold to the customer is approximately 4 ¢/kWh more than the cost to generate the electricity, the price of electricity from a new IGCC coal plant is approximately ¢13/kWh.

Cost of New Combined-Cycle Natural Gas Electricity Generation

Capital Cost. Table 17 shows the projected overnight costs for proposed and recent gas-fired combined cycle power plants; each estimate is discussed below.

Florida Power & Light's estimate is for the construction of a 1,219 MW combined cycle generating unit as an addition to the West County Energy Center. In filings with the Florida Public Service Commission, the estimated total installed cost for the project is $864.7 million in 2011 dollars. This total includes $41.6 million for transmission interconnection and integration and $87.3 million in allowances for funds used during construction (AFUDC) (FP&L, 2008). Excluding the transmission interconnection and the allowance for funds used during construction, this provides a total overnight cost of $736 million in 2011 dollars or $715/kW in 2010 dollars. When transmission costs are included, the total overnight cost increases to $755/kW.

Cost data on other plants listed in Table 17 are as cited in Du and Parsons (2009) updated to 2010 dollars. It is not clear whether these estimates include transmission or not.

Table 17: Overnight Costs for Proposed Combined Cycle Natural Gas Power Plants

Owner	Name	Design	Capacity (MW)	Projected Commercial Operation Date	Overnight Cost (2010$/kW)	Estimate Date
PE Carolinas	Richmond	2-on-1	570	2011	1,350	2008
NCPA	Lodi	1-on-1	255	2012	1,140	2008
CPV	Vaca Station	2-on-1	660	2013	760	2008
Macquarie	Avenal Energy Project	2-on-1	600	2012	940	2008
NV Energy	Harry Allen	2-on-1	500	2012	1,300	2008
Florida P&L	West County	3-on-1	1,219	2011	755	2008

Operation and Maintenance Costs: Operation and maintenance costs occur each year that the plant is in operation and are often disaggregated into fixed and variable costs. Estimates of O&M costs from various sources are shown in Table 18.

Table 18: Natural Gas O&M Costs

Source	Fixed ($2010/kW)	Variable ($2010/MWh)
DOE, 2007	11.05	1.49
Black & Veatch, 2007	16.21	3.38
Du and Parsons, 2009	14.21	4.48

Fuel Costs: The price of natural gas used to generate electricity is shown in Figure 5 for 2002 to 2009 (US DOE, 2009).

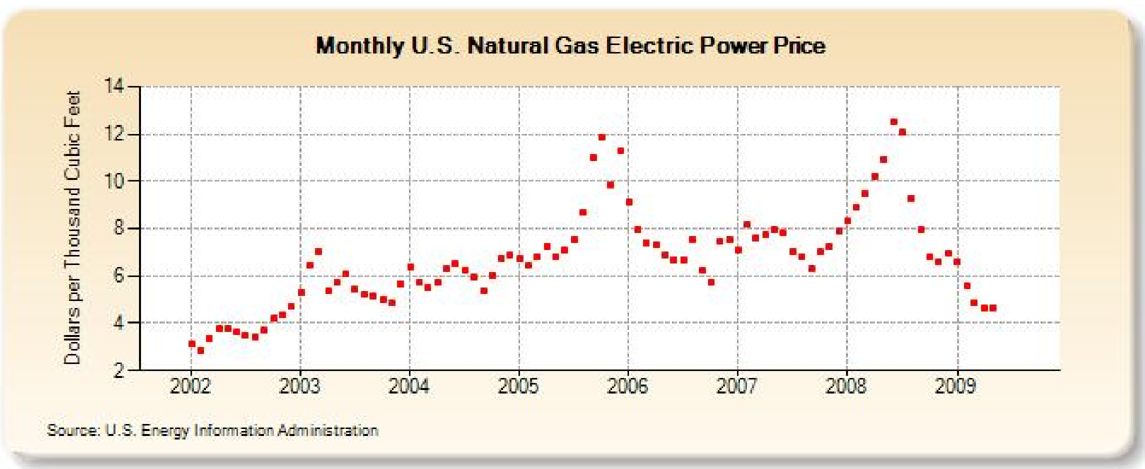

Figure 5: Price of Natural Gas for Electric Power

Natural gas prices have dropped significantly since peaking above $12/thousand cubic feet in mid 2008 (1000 cubic feet = 1.039 MMBtu). The US DOE has estimated the cost of natural gas delivered to electric utilities to stabilize at about $6/MMBtu in 2010 and remain unchanged in real term through 2035 (US DOE 2009). To indicate the impact of fuel costs, we use a natural gas fuel price range of $5/MMBtu to $7/MMBtu. Most of the range of our estimate is due to this fuel price range; higher or lower fuel prices would result in higher or lower electricity prices from natural gas powered plants.

Other Costs: Several other costs are sometimes included when calculating the levelized cost of electricity, including incremental capital costs and decommissioning costs.

Levelized Cost of Electricity: Table 19 shows our estimate of the levelized busbar cost of electricity from new combined cycle natural gas power plants.

Table 19: Estimated Cost of Electricity from New Gas Power Plants

Nameplate Capacity (MW)	600
Capacity Factor	.85
Nominal Discount Rate	7%
Book Life (years)	30
Plant Life (years)	50
Heat Rate (Btu/kWh)	6,800
Capital Cost ($/kW)	600 – 1,300
Fixed O&M ($/MW)	15
Variable O&M ($/MWh)	4
Fuel Cost ($/MMBtu)	5 - 7
Calculation Type	Carrying Charge = 15%
LCOE ($/MWh)	50 - 75

There is a considerable range in both the potential capital cost and the potential fuel costs for natural gas combined cycle plants. Figure 6 shows the sensitivity of the LCOE from natural gas with respect to fuel and capital costs. The figure shows an increase of approximately $20/MWh in the LCOE when fuel costs increase by $3/MMBtu and an increase of approximately $6/MWh when capital costs increase by $350/kW.

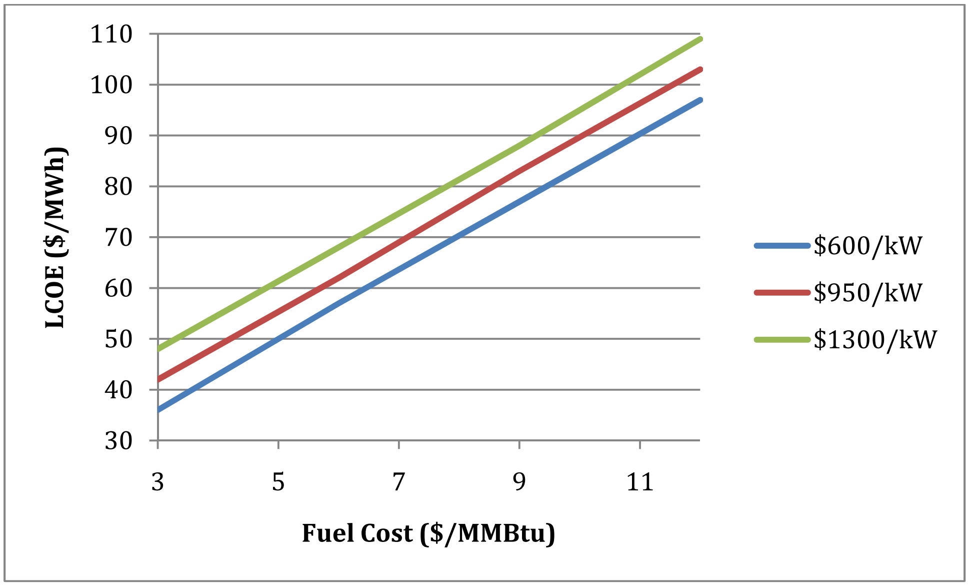

Figure 6: NGCC LCOE Sensitivity to Fuel and Capital Costs

Retail Price: Assuming the price of electricity sold to the customer is approximately 4 ¢/kWh more than the cost to generate the electricity, the price of electricity from a new natural gas combined cycle plant is between 9.0¢/kWh and 11.5¢/kWh.

Cost of New Biomass Electricity Generation

Here we consider the cost of building completely new biomass-fueled power plants. There are a number of existing fossil-fueled power plants that are being converted to biomass; those costs can be expected to be smaller than the cost of electricity from completely new plants. In addition, co-firing of biomass with coal can also be expected to be less expensive than building new plants. However, plant conversion and co-firing maintain existing capacity with a different fuel, rather than producing new capacity.

<u>Capital Cost</u>. Table 20 summarizes data on the overnight costs of constructing a biomass plant.

In a filing with the U.S. Securities and Exchange Commission, Oglethorpe Power reported that it will spend $930 million to build two 100 MW biomass-fired power plants in Georgia, with expected in-service dates of 2014 and 2015 (SEC 2009). This estimate includes financing costs; thus an upper limit on the overnight cost is $4,650/kW. This plant will use a fluidized bed boiler and steam turbine. Existing biomass power plants have heat rates ranging from 11,000 to 20,000 Btu/kWh (Wiltsee 2000). Here we assume a heat rate of 11,000 Btu/kWh, which may overestimate the efficiency.

Southern Company is building a 100 MW biomass plant, the Nacogdoches Generating Facility in Sacul, Texas, which is reported to cost $475-$500 million. This implies an upper limit on the overnight cost of $4750-$5000/kW (Southern Company 2009). This plant will use a fluidized bed boiler and steam turbine and we assume a heat rate of 11,000 Btu/kWh.

Biomass Power and Electric is proposing to build a 42 MW biomass plant in Port St. Joe, Florida (BG&E, 2008). The plant will cost an estimated $160-200M (Croft 2009). This indicates an upper limit on the overnight cost of $3800-$4760/kW. This will be a biomass integrated gasification combined cycle (BIGCC) power plant, with a projected heat rate of 7,200 Btu/kWh, according to permit filings with the Florida Department of Environmental Protection (FL DEP 2009).

Previous sources have estimated lower capital costs. Haq (2002) assumes an overnight cost of $1,536/kW in 2000 dollars. This translates to an overnight cost of approximately $2,100/kW in 2010 dollars. The total cost of construction is estimated to be $2,300/kW (in 2010 dollars) in 2000 but decrease to $1,750/kW (in 2010 dollars) by 2020. IEA (2000) reports a capital cost from $1,500/kW to $3,000/kW. Assuming these are in 2007 dollars, the range becomes $1,600/kW to $3,300/kW in 2010 dollars.

Table 20: Reported Overnight Costs for Biomass Electricity Generation

Source	Reported Overnight Cost ($2010/kW)
Oglethorpe, GA (2009)	4,650
Southern Company Nocogdoces TX (2009)	4,900
Biomass Power & Electric, Port St. Joe, FL	4,290

Operation and Maintenance Costs: Operation and maintenance costs occur each year that the plant is in operation and are often disaggregated into fixed and variable costs. Estimates of O&M costs from various sources are shown in Table 21.

Table 21: Biomass O&M Costs

Source	Fixed ($2010/kW)	Variable ($2010/MWh)
Haq (2002)	60.4	3.9

Fuel Costs: For the state of Georgia, the price of wood residue and wood chips delivered to bioelectric power plants has been estimated to be $3/MMBtu, in 2007 dollars, assuming a freight distance of 50 miles (Shumaker et al. 2007). That same study evaluates other potential biomass feedstocks in Georgia, ranging in delivered price from $1.09 for pecan hulls to $6.51 for switchgrass. Another source reports that in the southeast, wood residues cost $20/wet tonne, delivered to the power plant, which if the moisture content is 50%, would be approximately $44/dry tonne. For an energy content of 16 MJ/dry kg, this is $2.9/MMBtu (Reisert 2009).

Haq (2002) uses assumed fuel costs from the National Energy Modeling System (NEMS). Energy crops and forestry residues are estimated begin to make a significant contribution to total biomass availability at plant-gate prices around $2.30/MMBtu. Haq estimates that the majority of biomass resources are estimated to be available for electricity generation at a price of $4/MMBtu.

Other Costs: Several other costs are sometimes included when calculating the levelized cost of electricity, including incremental capital costs and decommissioning costs.

Levelized Cost of Electricity: Table 22 shows our estimate of the levelized busbar cost of electricity from new biomass power plants.

Table 22: Estimated Cost of Electricity from New Biomass Plants

	Conventional	**BIGCC**
Nameplate Capacity (MW)	100	42
Capacity Factor	.85	.85
Nominal Discount Rate	7%	7%
Book Life (years)	30	30
Plant Life (years)	50	50
Heat Rate (Btu/kWh)	11,000	7,200
Capital Cost ($/kW)	4,650 - 4,900	4,290
Fixed O&M ($/kW)	60	60
Variable O&M ($/MWh)	4	4
Fuel Cost ($/MMBtu)	0.75 -4.0	0.75 – 4.0
Calculation Type	Carrying Charge = 15%	Carrying Charge = 15%
LCOE ($/MWh)	96 - 136	87 - 111

Retail Price: Assuming the price of electricity sold to the customer is approximately 4 ¢/kWh more than the cost to generate the electricity, the price of electricity from a new conventional biomass plant is between ¢13.6/kWh and ¢17.6/kWh in 2010 dollars. Under this same assumption, the price of electricity from a new BIGCC plant is between ¢12.7/kWh and ¢15.1/kWh in 2010 dollars.

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Appendix: Levelized Cost of Electricity Calculation

The levelized cost of electricity (LCOE) is a common and useful metric of the cost of electricity generation. It is calculated as the present value (PV) of a given cost stream divided by the present value of electricity that will be produced over the lifetime of the facility.

$$LCOE = \frac{PV[Costs]}{PV[Electricity\ Generation]}$$

Present Value of Costs

Present value (PV) is a metric that accounts for the time value of money by converting a cash stream into a single equivalent value. This effect stems from the fact that an investor would prefer to have a certain sum of money today as opposed to the same sum at a later date. To account for this, cash streams are related back to a present value through the application of a real discount rate (r_0).

$$r_0 = \frac{i - f}{1 + f}$$

Here i is the nominal discount rate, or the interest rate at which future cash flows are discounted by the investor, and f is the expected rate of inflation which is included to account for the diminishing purchasing power of a currency. The present value of a payment stream ($x_0, x_1, \ldots, x_n$) is thus,

$$PV = x_0 + \frac{x_1}{1 + r_0} + \frac{x_2}{(1 + r_0)^2} + \cdots + \frac{n}{(1 + r_0)^n} = \sum_{i=0}^{n} \frac{x_i}{(1 + r_0)^i}$$

Where, ($x_1, \ldots, x_i$) are costs occurring in time period i, and x_0 represents any initial or overnight costs. In the case of fixed annual costs occurring at the beginning of the year in year 1, $x_i = x$ is a constant for all i=[1,n] and this expression reduces to a simple geometric sum. The following closed form relation calculates the sum,

$$PV = \sum_{i=0}^{n} \frac{x_i}{(1 + r_0)^i} = x_0 + \frac{x}{r_0} . \left[1 - \frac{1}{(1 + r_0)^n}\right]$$

Present Electricity Generation

Present value of electricity generation is calculated by applying the present value methodology to electricity generation. For most generation technologies, it is usually appropriate to assume constant annual electricity output, y, therefore, we have

$$PV[Electricity\ Generation] = \frac{y}{r_0}.\left[1 - \frac{1}{(1+r_0)^{PL}}\right]$$

In our calculations PL is defined as the plant life of the plant, or the number of years it is expected to remain in operation. The discounting of electricity generation follows directly from the goal of calculating a levelized cost of electricity. This may cause some confusion, as the electricity itself is not discounted, but the cost per unit of generating the electricity is discounted.

Levelized Cost Analysis

The levelized cost of electricity (LCOE) of a particular generation technology is the cost per kWh that when applied to each kWh of electricity generated over the life of the plant generates a cost stream with a present value equivalent to the known present value of costs. This derivation is show below.

$$PV[Costs] = \sum_{i=1}^{PL} \frac{LCOE * y}{(1+r_0)^i} = LCOE * y * \sum_{i=1}^{PL} \frac{1}{(1+r_0)^i}$$

$$\therefore PV[Costs] = LCOE * y * \left[\frac{1}{r_0}\left(1 - \frac{1}{(1+r_0)^{PL}}\right)\right]$$

Rearranging this equation we find

$$LCOE(\$/kWh) = \frac{PV[Costs]}{\left[\frac{y}{r_0}\left(1 - \frac{1}{(1+r_0)^{PL}}\right)\right]} = \frac{PV[Costs]}{PV[Electricity\ Generation]}$$

Our levelized cost analysis includes six costs: cost of investment, fuel cost, fixed O&M cost, variable O&M cost, cost of carbon emissions, and cost of carbon capture and storage (CCS) when applicable. Each of these is assumed to be an annual cost that is constant in real dollars throughout time. These streams can then be rolled back into a present value and divided by the present value of electricity generation to calculate a levelized cost. The cost of investment is assumed to be paid annually through the book life of the plant, while the others costs run through the entire plant life.

Cost of Investment

The *total investment* (TI) required for a project is calculated by multiplying the estimated overnight cost of the generation technology per unit of power generation capacity by the planned plant capacity. This required capital is generally obtained through various financing mechanisms over a period of time and therefore interest and the time dependent value of money must be considered.

Our approach utilizes a *carrying charge rate* (c), which is a commonly used metric for approximating the sum total of all complex financial interactions involved in the financing a power plant. The carrying charge can be thought of as the total average annual cost of capital of the plant which encompasses costs such as the cost of debt, cost of equity, taxes, and depreciation. This approach is used by Katzer et al and Rosenberg et al to generate levelized cost estimates for different generation technologies [1] [2].

The carrying charge is expressed as a fixed percentage of total investment, which is paid annually over the book life (BL) of the plant. The annual *carrying charge* (CC) can be calculated as follows,

$$CC = TI \ \cdot c$$

As the carrying charge is a constant annual cost stream, its present value can be calculated as follows,

$$PV[Carrying\ Charge] = \frac{CC}{r_0} \cdot \left[1 - \frac{1}{(1 + r_0)^{BL}}\right]$$

In our analysis, the book life and plant life are not necessarily equivalent. The book life is the length of time over which initial capital costs have an effect. This includes the time for the plant to fully depreciate and for all financing to be paid in full. The plant life is the operational life of the plant, which generally exceeds the book life of a plant by a decade or more.

Katzer et al. use a carrying charge of 15.1% in their analysis of coal based power plants, which is based on several fundamental financial assumptions and calculated in accordance with the Electric Power Research Institute (EPRI) Technology Assessment Guide (TAG) [3]. Rosenburg, et al. calculate a carrying charge of 12.3% for Integrated Gasification Combined Cycle (IGCC), Natural Gas Combined Cycle (NGCC) and Pulverized Coal (PC) with assistance from Robert Williams of Princeton University, by applying a methodology outlined in the June 1993 EPRI TAG [4]. They acknowledge that a carrying charge of approximately 15% is widely used in literature for coal based plants, but use 12.3% for their own analysis. Our analysis assumes a 15% carrying charge for coal, natural gas and biomass based generation.

The literature does not directly address the calculation of a carrying charge for application to nuclear generation technologies. Based on the assumption that projects to construct nuclear power plants generally require more complicated financing mechanisms and hold much more risk than fossil power plants, we will use an augmented carrying charge of 18% for our analysis of nuclear electricity generation.

Additional Costs

Before outlining the calculations of the other five costs it is useful to define the annual electricity output (AEO) of a plant as follows, where 8760 is the number of hours in one year.

$$AEO = PC \cdot CF \cdot 8760$$

The other costs are then calculated as follows,

$$Annual\ Fuel\ Cost = FC \cdot HR \cdot AEO$$

$$Annual\ Fixed\ O\&M\ Cost = PC \cdot FO$$

$$Annual\ Variable\ O\&M\ Cost = VO \cdot AEO$$

$$Annual\ Carbon\ Cost = CO2C \cdot CO2E \cdot [1 - CCAP] \cdot HR \cdot AEO$$

$$Annual\ CCS\ Cost = (CCSC + CCST + CCSS) \cdot CO2E \cdot CCAP \cdot HR \cdot AEO$$

The result is five constant cost streams which are assessed annually over the plant life. Let z be the annual cost of any one of these components. The present value of each cost stream over the life of the facility is calculated by,

$$PV[Cost] = \frac{z}{r_0} \cdot \left[1 - \frac{1}{(1 + r_0)^{PL}}\right]$$

Levelized Cost of Electricity

The present value of these six costs are then summed and divided by the net present electricity generation to obtain a levelized cost of electricity,

$$LCOE = \frac{PV[Carrying\ Charge + Fuel + FixedO\&M + VariableO\&M + Carbon + CCS]}{PV[Electricity\ Generation]}$$

Input parameters used in the levelized cost calculation.

Parameter	**Units**	**Abbreviation**
Plant Capacity	MW	PC
Overnight Cost	$/kW	OC
Capacity Factor	%	CF
Heat Rate	btu/kWh	HR
Plant Life	Years	PL
Book Life	Years	BL
Carrying Charge	%	c
Inflation	%	f
Nominal Discount Rate	%	i
Fuel Cost	$/MMbtu	FC
Fixed O&M	$/kW/Year	FO
Variable O&M	mils/kWh	VO
Carbon Cost	$/tCO2	CO2C
Carbon Emissions	t/MMbtu	C02E
Carbon Captured	%	CCAP
CCS Compression/Pumping	$/tCO2	CCSC
CCS Transport	$/tCO2	CCST
CCS Storage	$/tCO2	CCSS

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